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On the origin of superparamagnetic minerals of tropical soils and their impact on landmine detection

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Magnetic susceptibility of soils is mainly determined by their content of ferrimagnetic minerals whereas titanomagnetite, magnetite and maghemite being the most important ones. Titanomagnetite and magnetite are of magmatic origin, i.e. they crystallise during cooling of iron-rich magma and are part of many igneous rocks. Maghemite and sometimes magnetite are of pedogenic origin. They develop by crystallisation of dissolved iron during soil forming processes. Ferrimagnetic minerals that are smaller than some tens of nanometres are superparamagnetic (SP) and show frequency dependent susceptibility. SP minerals crystallise if magma cools down rapidly (e.g. volcanic magmas, glasses and ashes) and are frequently formed during pedogenesis.

In order to investigate the origin and formation of SP minerals in tropical soils, we analyse magnetic properties of 594 samples from the entire tropics comprising the whole range of weathering states from unweathered rock to highly weathered soil. Tropical soils are subject to intense chemical weathering and are rich in ferrimagnetic and in particular SP minerals. The process leading to a high content of these minerals is either residual enrichment due to their weathering resistance or neo-formation. In this study we focus on the frequency dependent susceptibility (absolute and relative) of the samples and classify it according to the parent material and alteration. We observe that
• within each parent-material group, rock material shows in general lower susceptibility and absolute frequency dependence than soil material
• ultrabasic and basic/intermediate rocks and soils developed from these rocks show high absolute frequency dependent susceptibility and, in contrast, acid rocks and sediments show lower absolute frequency dependence
• absolute frequency dependence increases from unweathered rock to weathered rock, and from subsoil to topsoil material within every group of parent material
• relative frequency dependence rises successively with weathering for ultrabasic, basic/intermediate and acid igneous parent material, but, it tends to decrease for clay/clay slate and sandstone.
Based on the above observations we conclude that the content of SP minerals depends on both: parent rock and alteration of the material. The total amount of SP minerals rises during weathering, regardless of the parent material. The process is either preferential accumulation of weathering resistant magnetic minerals, including the ultra-fine grained fraction, or neo-formation of new magnetic minerals. The increase of relative frequency dependence of igneous rocks is a clear indication that SP minerals are formed during soil genesis. However, for some sedimentary rocks, the amount of SP minerals is already high and is not subsequently increased further during weathering.

Electromagnetic induction (EMI) based metal detectors are the most widely used sensing techniques in landmine clearance operations. They are negatively influenced by magnetic susceptibility and its frequency dependence. In particular tropical soils show to have a negative impact on EMI sensors. Besides, the tropics are the regions which are most affected by landmines where most of the humanitarian demining-activities concentrate. Currently, no soil classification system exists that helps to predict the influence of frequency dependent susceptibility on landmine detection. We deduce a system that can be used to predict the soil impact depending on parent material and weathering. Our system can be consulted by demining organisations to predict metal detector performance in tropical regions based on geologic and soil maps. Ultra-basic, basic and intermediate igneous rocks have a moderate influence on EMI detectors in average cases and a very severe influence in extreme cases.

Soils developed from these rocks have a severe or very severe influence. In contrast, acid igneous rocks and sediments do not influence EMI detectors severely. Soils developed from these rocks have no influence in average cases; however, they may have a very severe influence in extreme cases.